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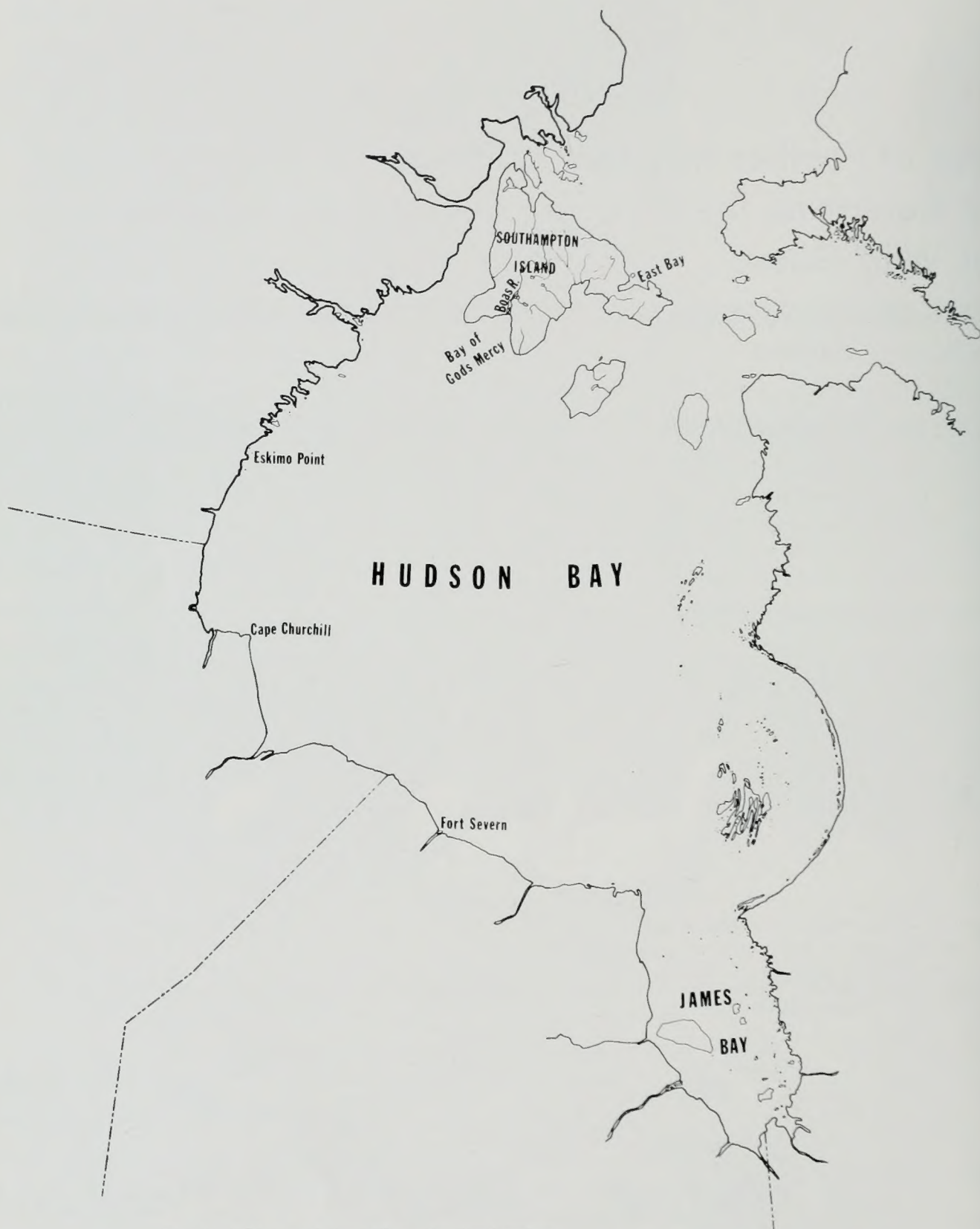


Fig. 1.—Hudson and James Bays, showing locations of study areas and features discussed in the text.

Use of Feather Minerals as Biological Tracers to Determine the Breeding and Molting Grounds of Wild Geese

HAROLD C. HANSON and ROBERT L. JONES¹

MOST POPULATIONS AND SUBPOPULATIONS of wild geese are distributed on their breeding grounds in discrete units that occupy distinct physiographic and geologic areas. The possibility that feathers of these various populations contain an assortment of minerals bearing some relationship to the occurrence of elements in the nutrient chain—parent rocks, soils, waters, and food plants—of the breeding grounds was suggested by studies made of the mineral content of the body and feathers of ruffed grouse (*Bonasa umbellus*) in New Hampshire.² It was found that a grouse could be associated with one of the four geological areas in the state by the content of minerals occurring in its tail feathers.

After we had confirmed, from studies beginning in 1965, that a similar relationship existed between the minerals in the primary feathers of all the races of Canada geese examined³ and the minerals in the ecosystems of their breeding grounds (Illinois Natural History Survey 1966), the study was extended to all species and races of wild geese breeding in or migrating into North America. In this report the analytical techniques used are described and the types of results obtained are illustrated by data for two populations of blue and lesser snow geese (*Anser caerulescens caerulescens*)⁴ which nest adjacent to Hudson Bay.

Waterfowl nesting in temperate and more northerly portions of the northern hemisphere undergo a precipitous molt of primary and secondary wing feathers. The molt occurs in breeding geese about 7–10 days after the young have hatched and about an equivalent time earlier in the nonbreeding birds. The time required for growth of new flight feathers is directly related to the size of the bird. In Canada geese (*Branta canadensis*), which range in weight from 3 to 18 pounds, the flightless period varies from about 24 to 42 days (Hanson 1965 and un-

published). For lesser snow geese this period is about 25 days.

The primary wing feathers were selected for analysis because their growth must be complete before the birds leave their natal area or, in the case of nonbreeding birds that have made a molt migration, their molting area. In contrast, the replacement of tail and body feathers may continue well into autumn and winter.

The likelihood of a distinctive regional profile of minerals being incorporated into the protein matrix of the feather is increased by the dramatic degradation and synthesis of muscle and bone that take place during the period of principal growth of the wing feathers. A recent study of Canada geese (Hanson 1962) has shown that by the midperiod of the molt the sternal muscles lose 25–41 percent of their weight and the leg muscles increase in weight 41–57 percent, depending on age and sex. By the time flight is resumed, the weights of these muscle groups are almost back to normal. The degradation of the sternal muscles appears to be a survival-related evolutionary development whereby amino acids, particularly the sulfur amino acids, are made available for rapid feather growth. The hypertrophy of the leg muscles, however, reflects their temporarily increased use.

In addition to these dramatic changes in mass of the muscles, dynamic changes in the mineral metabolism of the muscle tissues also take place (Hanson and Johnson, unpublished). The deposition and high turnover of medullary bone during egg laying in birds is well documented (Sturkie 1965: 491–501); less well understood is the osteoporosis of the long bones of the leg, particularly the tarsi, that takes place during molt (Meister 1951; Hanson unpublished).

As a result of these various degradational processes, a high turnover of some minerals and selective conservation of others is implicit during molting and breeding cycles.

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¹Dr. Harold C. Hanson is a Wildlife Specialist at the Survey. Dr. Robert L. Jones is a Soil Mineralogist at the University of Illinois College of Agriculture.

²Studies by Robert A. McCullough and C. L. Grant in 1952–1953 in connection with Pittman-Robertson—Dingell-Johnson projects involving laboratory analyses of fish and game and their foods.

³Studies in progress by the senior author indicate the existence of 20, rather than the currently recognized 12, races of Canada geese.

⁴Most authorities now recognize the blue goose and lesser snow goose as color phases of the same subspecies.

eries and Wildlife who called his attention to the grouse studies of McCullough and Grant in 1962 during discussions of taxonomic problems in Canada geese.

For logistic support and aid in collecting specimens, we are grateful to Harry G. Lumsden, John Lessard, and C. E. Perrie of the Ontario Department of Lands and Forests; Eugene F. Bossenmaier of the Manitoba Department of Mines and Natural Resources; and G. C. Wilson, Rocket Range Officer, National Aeronautics and Space Administration, at Churchill, Manitoba. Dr. F. Graham Cooch of the Canadian Wildlife Service advised us on the origin of the blue and lesser snow geese collected at Fort Severn, Ontario.

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STUDY AREAS, MATERIALS, AND METHODS

The blue and lesser snow geese for which data on feather minerals are reviewed here breed adjacent to Hudson Bay at Cape Churchill, Manitoba, and on Southampton Island, N.W.T. (Fig. 1).

The Cape Churchill colony is unique in several respects. It is of very recent origin, possibly dating from 1962 when Harry G. Lumsden and the senior author observed a few dozen birds in the area. We know of no records of the existence of a colony of appreciable size prior to that year. In 1966, aerial photographs of a large percentage of the flightless adults and their downy young, and estimates of the remainder, indicated that the colony contained 5,000–6,000 geese. The feeding range of this colony is restricted to a roughly triangular area that flanks Hudson Bay for a distance of about 13 miles west of the Cape and extends for 7 miles south of it.

All of the major colonies of lesser snow and blue geese in the Canadian Arctic occupy areas of earlier marine submergence, but they are locally situated either on braided river mouths or on delta islands. Although subject to tidal flooding along the seaward edges, these areas are constantly flushed by fresh water. In contrast, emergence of the Cape Churchill colony site from the waters of Hudson Bay may be as recent as 1,000 years ago.¹ The area is low, subject to periodic extensive tidal flooding, and drained only by a few small streams. The

geese feed near the coast, both within the tidal zone and in the adjacent salt marsh.

The soils of the area and the silt and clay sediments in which they developed are highly calcareous, having been derived from calcareous Silurian sedimentary rocks underlying the Cape.

The blue and lesser snow geese that feed along the south coast of Hudson Bay each autumn in the vicinity of Fort Severn, Ontario, originate from two colonies on Southampton Island—one at the apex of East Bay and the other at the mouth of the Boas River which empties into the Bay of Gods Mercy (F. Graham Cooch, personal communication). Probably the wing samples that we studied from geese shot at Fort Severn chiefly represented the much larger, Boas River colony.² Geologically, both areas are similar, being underlain by limestone of Ordovician and Silurian ages (Armstrong 1947). According to Manning (1942), the nests of this colony "are situated almost entirely on grassy islands in the mouth of the Boas River. . . . At its mouth, the river is at least two miles wide, and in July is so shallow that it can be crossed in knee boots; but during the spring it is greatly swollen. On both banks the river is bounded by about eight miles of flat marshland which terminates in disintegrated limestone ridges."

In our studies only the vane portions of the primary feathers were used in the analyses because they were found to be more highly mineralized than the shaft. The basal quarter of the vane was also excluded because part of this portion of the feather is grown after the goose has regained the power of flight (Hanson 1962) and could possibly, although unlikely, have left the breeding or molting area. In this case it would be possible for a somewhat different mineral pool to be incorporated into the basal portion of the feathers.

To facilitate washing, the remaining portions of the primary feathers were cut transversely into 1½-inch pieces. These were washed with distilled water by shaking in 250 ml conical flasks for at least 4 hours and then rinsed several times with distilled water. The flasks and contents were then drained of excess water and dried in an oven held at 60° C. for at least 24 hours. Approximately 1 gram of the dried vane was trimmed free of the shaft and placed in a 50-ml Vycor crucible.

Analytical determinations were performed with a Jarrell-Ash direct reading emission spectrograph on an acid solution (containing 4.5 percent HCl and 1.5 percent HNO₃, both by volume, and 1 percent lithium as LiCl) of the dry-ashed (500° C.) sample. A rotating-disc solution technique with a-c spark excitation was used with lithium as an internal standard. The content of each element was estimated from working curves obtained from reference plant samples.

¹Aerial observations indicated that the main feeding grounds of this colony lie well within the 25-foot elevation level (Cape Churchill Sheet, 54 K, 4 mile-1 inch topographic series, Canadian Department of Mines and Technical Surveys). This date assumes a rate of postglacial uplift of 75 centimeters per 100 years (Barnett 1966).

²This feather collection undoubtedly contained primaries of a few geese from the colony at Eskimo Point. A definitive report on the biogeochemistry of all breeding colonies, based on birds collected either on their breeding grounds or banded there during the molt and shot elsewhere, is under preparation.

RESULTS AND DISCUSSION

The results of the feather analyses are given in Table 1, and levels of significance (P) for differences between means using the "t" test are tabulated in Table 2.

Few facts of a fundamental physiological nature can be deduced from these data at this time. The slightly higher levels found for most minerals in adults are, however, of interest. Many clear distinctions in mineral concentration can be made between the Cape Churchill and Southampton Island goose populations that are valuable for the practical purpose of determining the origin of a goose. The higher sodium, potassium, calcium, and magnesium values for the Cape Churchill geese reflect close association with the tidal and brackish water conditions and higher content of mineral elements in this environment, whereas the lower values for Southampton Island geese reflect the traditional inland movement to fresh-water areas of these birds after hatch (Bray 1943). Our accumulating data from breeding areas, from which we have ascertained the chemical composition of the soils and food plants as well as feathers of the populations concerned, clearly indicate that the higher values for phosphorus, manganese, silicon, aluminum, and boron in the feathers of the Southampton Island geese must be associated with an intake of food plants, soils, and grit proportionately more abundant in these elements. The invariant nature of zinc

and copper in these two populations probably reflects physiological control in environments low in these minerals. In general, the levels of significance (Table 2) for the adults and for the immatures between the two populations are similar; those data showing wide differences reflect variability and wide range in the analyses.

There is a close similarity of values for adults and immatures from each locality (Table 1). This similarity contradicts the possibility that data for adults are not likely to be meaningful because the birds return north with a highly differentiated body pool of minerals and grit in the gizzard after 6–8 months of feeding in other environments. Evidently, the 1–2 months the adults spend on their breeding grounds prior to the molt is sufficient time for a new balance to be achieved between their mineral pool and the new environment. The possibility of genotypical differences between the two populations as a factor in explaining, at least in part, differences found in feather chemistry can also be dismissed because the Cape Churchill population is of very recent origin and was very likely derived from Eskimo Point colony stock (Fig. 1) which in turn is thought to have originated from Southampton Island stocks.

There is little information in the literature on the mineral content of feathers. In his summary of animal nutrition Mitchell (1962:229) was able to cite only Gonnermann (1918) with respect to mineral content

TABLE 1.—Analyses (ppm), standard error of the mean, and range of the analyses of vane portions of blue and lesser snow goose feathers. (Negative values correspond to values less than figures stated. For computation, the negative sign was ignored.)

<i>Cape Churchill, Manitoba</i> (locally breeding stocks)							<i>Fort Severn, Ontario</i> (stocks breeding on Southampton Island, N.W.T.)						
Adults (N=11)			Immatures (N=5)				Adults (N=18)			Immatures (N=10)			
Mean	S _x	Range	Mean	S _x	Range		Mean	S _x	Range	Mean	S _x	Range	
Na ...	581	18	445–644	536	30	441–606	237	11	172–315	231	14	160–298	
K ...	670*	191	153–1,623	822**	251	443–1,296	65	14	16–300	43	3	21–54	
Ca ...	1,809	111	1,500–2,800	1,900	141	1,600–2,400	1,417	70	600–2,000	1,310	72	900–1,600	
P	204	12	-150–250	200	16	-150–250	264	22	150–500	280	21	200–400	
Fe ...	82	16	10–219	71	8	54–95	189	15	68–314	170	26	78–303	
Zn ...	116	2	106–124	113	3	104–121	117	3	81–130	116	2	103–128	
Mg ..	568	38	450–900	550	39	500–700	342	12	300–500	340	37	300–400	
Mn ..	3.2	0.5	2–8	3.2	0.2	-3–(-4)	5.6	0.8	-2–10	4.6	0.8	-2–9	
Cu ..	7.0	0.3	5–8	7.2	0.7	6–10	6.9	0.4	5–10	6.6	0.3	6–8	
Si ...	1,818	788	-1,000–9,700	1,220	97	-1,100–1,600	2,256	373	-1,000–5,700	3,150	946	-1,000–8,600	
Al ...	21	2.7	-12–78	16	1.1	-14–20	85	9	31–150	83	17	16–174	
B	2.6	0.2	4–9	3.4	0.2	3–4	4.8	0.4	3–7	4.3	0.2	4–6	

*N=7
**N=3

TABLE 2.—Values for P comparing adults and immature birds within populations and each age group between populations, blue and lesser snow geese.

	Cape Churchill Adults vs. Immat.	Fort Severn Adults vs. Immat.	2 Areas Adults	2 Areas Immat.
Na .....	.20	.75	<.01	<.01
K .....	.71	.35	<.01	<.01
Ca .....	.64	<.01	.03	<.01
P .....	.87	.65	.06	.03
Fe .....	.66	.44	<.01	.02
Zn .....	.64	.82	.80	.42
Mg .....	.87	.95	<.01	<.01
Mn .....	.60	.58	<.01	.22
Cu .....	.78	.63	.88	.37
Si .....	.62	.32	.59	.18
Al .....	.24	.91	<.01	.01
B .....	.01	.38	<.01	.01

of feathers. The latter found that silicon (as SiO_2) may account for as much as 77 percent of the ash of the primary feathers of ring doves (*Streptopelia roseogrisea*) (presumably captives). We assume that most minerals have been bonded to the protein matrix of the keratin via free charges on the amino acids rather than physical adsorption or exchange on the surface of the feather. Possibly some minerals occur as salts of acids. Certain elements are known to have a competitive and others a reciprocal relationship to organic binding sites; others may be substitutive. We suspect, however, that binding rates of the various ions at the feather follicle (anlage) tend to follow the law of mass action.

In addition to the several recognized ways that minerals in the diet in amounts greater than body needs are excreted—by way of the alimentary canal, kidneys, and the salt or nasal glands (Na^+ only)—it clearly appears that the feather protein is a fourth avenue of excretion of excess minerals. The data for the two snow goose colonies suggest that wild geese maintain normal physiological functions under widely varying rates of mineral intake. No firm conclusions can be made at this time as to either the limits of the capacity of wild geese to utilize feather keratin as a mode of mineral excretion or the nutritional significance of excretion rates via the feather follicle. The actual mode and sequence of events responsible for mineral incorporation into the feather do not appear to be particularly relevant to the initial practical objective of the study, i.e., to be able to determine the origin or birthplace of individual birds

or populations in autumn and winter. This objective is particularly significant to management of lesser snow and blue goose populations, most of which are indistinguishable morphologically, although the birds breed in widely separated colonies.

More feather elements differ significantly between these two populations than is the case for similar comparisons between some other populations we have studied. However, the technique is useful if the population in question can be differentiated from all others by only one element. Obviously a population distinctive in two or more elements is more readily identified, and a spectrum of 12 elements, theoretically, should permit a great number of distinctive mineral "profiles" to be distinguished among all populations. However, variability within most populations considerably limits the actual number of distinctive permutations likely to occur.

Banding has made enormous contributions to our understanding of the distribution and seasonal movements of birds, but the shortcomings of this technique are manifest—chiefly, the fact that bandings in any one year are parochial in representation and the application of band recovery data often involves tenuous statistical assumptions and corrections. It is hoped that the technique and findings reported here will open a new era of more refined identification and management of waterfowl populations (Fig. 2). Although the method described involves complex and expensive instrumentation, our data for color of the feather ash (Jones and Hanson, unpublished) of the various populations of lesser snow and blue geese indicate that some are also "color coded" to their birthplace or breeding area. To identify these it is only necessary to wash the clipped vanes of the primary feathers, burn them to ash in a muffle furnace, and carefully note the color (Munsell or some other notation system) to establish the birthplace.

Studies of trace minerals occurring in natural populations, whether in keratin structures or body structures, have considerable potential. For example, the hypothesis has been advanced that soil calcium is a limiting factor in the southward distribution of the ring-necked pheasant (*Phasianus colchicus*) in the United States (Leopold 1931:125). Because the amount of a mineral in feathers appears to be an expression of the extent to which it occurs in excess of metabolic needs in the nutrient chain, feather calcium or its ratio to some other element or elements may provide new insight into the question of pheasant range limitations.

Feather analysis may be useful in a wide range of nutritional studies because results can be obtained without sacrificing the experimental individuals. Prior to the present studies, Dr. Harold M. Scott of the College of Agriculture, University of Illinois, and the senior author held three groups of Canada geese on experimental rations that differed in only two respects—in methionine content and including a supplement of MgSO_4 —from the diet containing the standard mineral mix used at the College in experimental feeding



Fig. 2.—Lesser snow and blue geese in a cornfield on the Squaw Creek National Wildlife Refuge in northwest Missouri. The changing habits of these geese and increasing kills made by hunters at points along the migration routes emphasize the need for better information about the origins of such populations.

of poultry. Fortunately the primary feathers from these geese, which were sacrificed, were saved, partly because it was noted at the time that they had not developed normally, being more curved and “foreshortened” than feathers of normal wild birds. Therefore it was of interest to note that the feathers of all three experimental groups of geese revealed much lower contents of most of the minerals we analyzed for than were found in any wild populations thus far studied. These findings suggest that an ultimate of economy in the design of poultry rations may have been approached, but the data also raise the question of whether or not the highly enriched diets of wild birds could play a role in their tremendous vigor and recuperative powers.

To answer the many questions which this preliminary study raises, all factors in the nutrient chain in the ecosystem will have to be studied. For a number of localities in the Arctic we have analyzed samples of the soil, plant food, feathers, and feces. These analyses are providing insights unlikely to be obtained by studies of caged birds alone.

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